TECHNICAL NOTES

1. General Description of Aluminum Electrolytic Capacitors

1-1 Principle of Capacitor Construction

The principle construction of a parallel plate capacitor is shown in Fig.1.

When a voltage V is applied between the conducting electrodes placed opposite to each other, a certain amount Q of electric charge proportional to the voltage can be stored on the surfaces of the dielectric. The proportional constant is called capacitance C, designating the ability of a capacitor to store energy in an electric field.

Q=C.V
Q: Charge(C)
V: Voltage (V)
C: Capacitance (F)

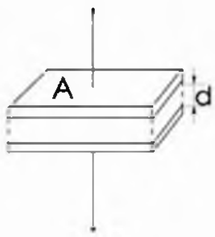


Fig. 1

The capacitance C of capacitor can be expressed by the following equation:

$$C = \varepsilon 0 \cdot \varepsilon \cdot A/d$$

ε: dielectric constant
ε0: dielectric constant in vacuum (= 8.85×10^{-12} F/m)
A: electrode area [m2]
d: electrode distance [m]

The dielectric constant of an aluminum oxide layer is 7 to 8. Larger capacitances can be obtained by enlarging the electrode area A or by reducing the distance d.

Table 1 shows the dielectric constants of typical dielectrics used in capacitors. In many cases, capacitor names are related to their dielectric material used, for example, aluminum electrolytic capacitor, tantalum capacitor, etc.

Table 1

Dielectric	Dielectric Constant	Dielectric	Dielectric Constant
Aluminum oxide film	7 to 8	Porcelain(ceramic)	10 to 120
Mylar	3.2	Polypropylene	2.2
Mica	6 to 8	Tantalum oxide film	10 to 20

Aluminum electrolytic capacitors offer large volumetric capacitance values, because the anode electrode's surface is roughened by electrochemical etching, enlarging its area by factor of 20~100 compared to plain foil, and also because the dielectric layer is very thin (1.4 nm/V).

The schematic cross section of an aluminum electrolytic capacitor is shown in Fig. 2

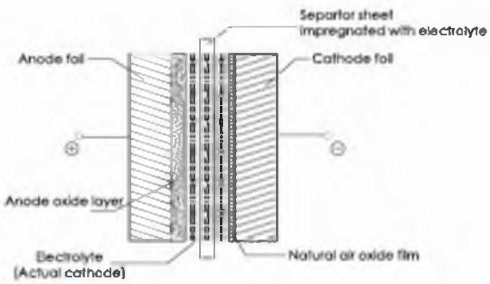


Fig. 2

1. 铝电解电容器的基本概要

1-1. 电容器的结构原理

平行板电容器的基本结构原理可以用图1-1来描述。

当一个电压V施加在彼此正对的两块导电极板两端时，与电压成正比的电荷量Q将被储存在电介质的表面。这个用来标称电容器在电场中储能能力的比例常数被称作容量C。

Q=CV
Q:电量(C)
V:电压(V)
C:电容量(F)

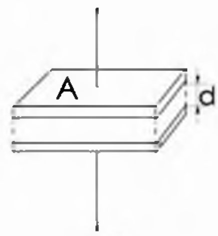


图 1

电容器的容量可以用以下公式来表示：

$$C = \varepsilon 0 \cdot \varepsilon \cdot A/d$$

ε: 电介常数
ε0: 真空中的电介常数(= 8.85×10^{-12} F/m)
A: 极板面积 [m2]
d: 极板距离 [m]

铝氧化膜的相对介电常数为7~8，要想获得更大的电容，可以通过增加表面积A或者减少其厚度d来获得。

表1-1列出了电容器中常用的几种典型介质的相对介电常数，在很多情况下，电容器的命名通常是与介质所使用的材料相关的，例如：铝电解电容器、钽电容器等。

表 1

介质	相对介电常数	介质	相对介电常数
铝氧化膜	7 ~ 8	陶瓷	10 ~ 120
薄膜树脂	3.2	聚丙烯	2.2
云母	6 ~ 8	钽氧化膜	10 ~ 20

电容器的电极表面通过电化学腐蚀变得粗糙，从而使面积比光箔扩大了20~100倍，同时电介质层的厚度非常小（1.4纳米/伏），因此铝电解电容器可以提供非常大的体积容量。

图1-2是铝电解电容器的切面示意图。

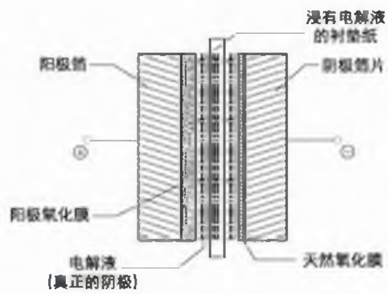


图 2

1-2 Equivalent Circuit of the Capacitor

The electrical equivalent circuit of the aluminum electrolytic capacitor is given in Fig.3

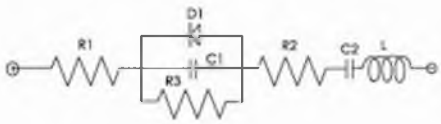


Fig. 3

R1: Resistance of terminal and electrode
R2: Resistance of anode oxide layer and electrolyte
R3: Insulation resistance because of defective anodic oxide layer
D1: Oxide semiconductor of anode foil
C1: Capacitance of anode foil
C2: Capacitance of cathode foil
L: Inductance caused by terminals, electrodes, etc.

1-2 电容器的等效电路

电容器的等效电路图可由下图3表示

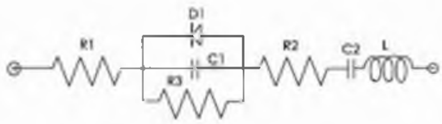
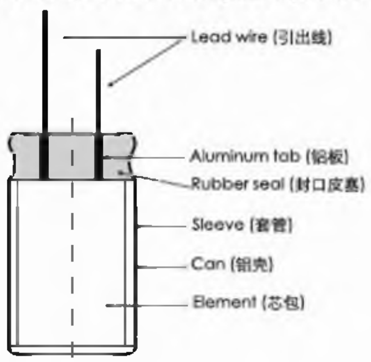


图 3

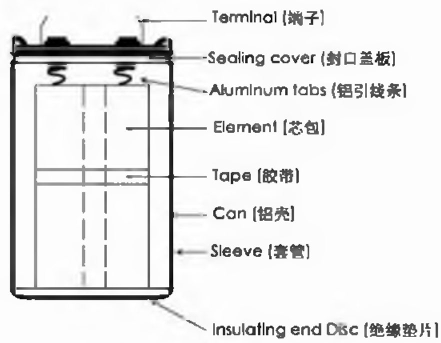
R1：电极和引出端子的电阻
R2：阳极氧化膜和电解质的电阻
R3：损坏的阳极氧化膜的绝缘电阻
D1：具有单向导电性的阳极氧化膜
C1：阳极箔的容量
C2：阴极箔的容量
L：电极及引线端子等所引起的等效电感量

1-3 Structure of aluminum electrolytic capacitor

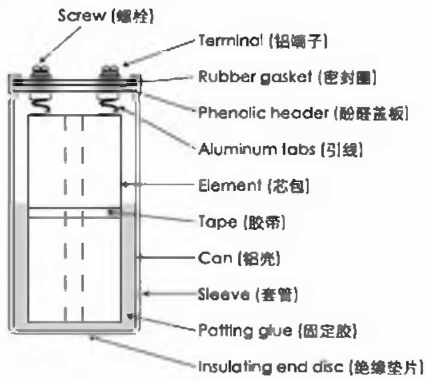
1-3 铝电解电容器的结构



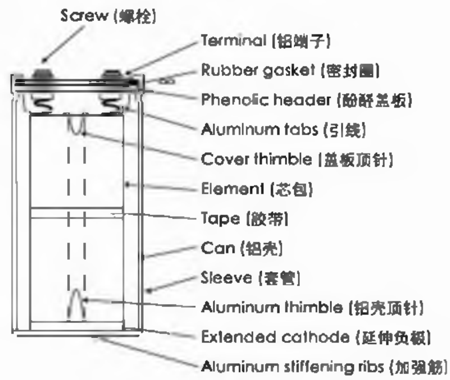
Radial Type (引线式)



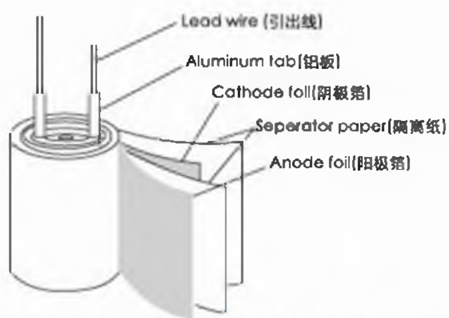
Snap-in Type (焊针式)



Screw Type-glue fixing (螺栓式-固定胶固定)



Screw Type-thimble fixing (螺栓式-顶针固定)



Construction of Element (芯包展开图)

1-4 Manufacturing process of aluminum electrolytic capacitors

Process	Main Materials	Content
Etching (Enlargement of the Surface Area)	High purity aluminum foil Chloride Pure water	A 0.05~0.11 mm thick anode foil and a 0.02~0.05 mm thick cathode foil are continuously etched electrochemically in a chloride solution with an AC or DC current. This enlarges the effective surface area of the aluminum foils to attain smaller capacitor sizes.
Forming (Formation of the Dielectric)	Etched foil Borate, etc. Pure water	This process builds the aluminum oxide (Al2O3) layer that becomes the capacitor' s dielectric. A high purity etched aluminum foil is anodized in a (for example) solution made of water, boric acid, and ammonium, to form an aluminum oxide layer on the surface of the anode foil. For the cathode foil, a low DC voltage is sometimes used for formation, but sometimes no formation is done at all.
Slitting	Anode foil Cathode foil	A foil is slited into specified widths according to capacitor case sizes.
Winding	Slited foils (anode/cathode) Electrolytic paper Lead Winding affixing material	Anode and cathode foils interleaved with an electrolytic paper are wound into a cylindrical capacitor element, with aluminum tabs being connected to both foils.
Element Impregnation Electrolyte	Elements Electrolyte	Elements are impregnated with liquid electrolyte.
Assembly & Finishing	Impregnated elements Case (usually aluminum) End seal (Rubber packing, Rubber-bakelite with terminals Mold plastic with terminals) Exterior housing material (Sleeving, bottom plate, etc.)	The impregnated element, case and end seal are assembled.
Aging	Assembled products	DC voltage is applied under high temperature conditions to reform the oxide layer.
Processing	Taping material Accessories (Capacitor mounting braket, terminal screws, etc.)	Depending on customer specification, the lead cutting, forming and taping are processed. Accessories, such as mounting bracket, are attached.
Inspection		A 100% inspection based on the specification standards and test requirements is performed to guarantee the quality of products.
Packaging	Packaging materials	
Shipping		

1-4 铝电解电容器制造流程

工序	主要原料	内容
腐蚀（增加表面积）	高纯铝箔 氯 纯水	用交流或直流将0.05~0.11毫米厚的阳极箔，0.02~0.05厚的阴极箔连续不断地放在氯溶液进行电化腐蚀，这种方法使铝箔的有效表面积得以增大，以实现电容器的小型化。
化成（形成电介质）	腐蚀箔 硼酸盐等 纯水	在这一工艺过程中生成铝氧化层(AL2O3)作为电容器的电介质。高纯腐蚀箔在硼酸铵溶液中进行化成，在阳极箔的表面上形成铝氧化层。对于阴极箔来说，有时也会进行直流低压化成，但有时根本不进行化成。
分切	阳极箔 阴极箔	根据电容的不同高度，铝箔被分切成规定的宽度。
卷绕	分切好的铝箔 电解纸 引线 卷绕中的粘贴材料	阴极箔，阳极箔中间隔一层电解纸被卷成一个圆柱形的电容器芯包，并在两种箔上铆上引线。
芯包在电解质中浸渍	芯包 电解液	芯包在液体电解液中浸渍
组装和后处理	浸好的芯包 铝壳 封口密封件 外壳上用的材料	把浸好的芯包，铝壳和密封材料组装起来
老化	组装好的产品	在高温条件下施加直流电压以重新形成氧化层
后处理	编带材料 附件 （电容器安装支架，终端螺丝等）	根据客户的技术规范要求，完成引线切脚、成型和编带，安装卡环等配件
检验		根据技术标准和测试要求进行100%检测，以确保产品的质量
包装	包装材料	
发运		

1-5 Basic parameters and terms

1-5-1 Capacitance:

The capacitance of the dielectric portion of the anode aluminum foil can be calculated with the following formula:

$$Ca = 8.855\times10^{-8}\frac{\varepsilon\cdot A}{d}\ (uF)$$

The cathode foil capacitance Cc depends on the dielectric properties of the oxide layer which was either deposited by a forming voltage or which grew naturally during storage (typically, the voltage proof of the cathode oxide layer is 1V or less). According to the construction of aluminum electrolytic capacitors, Ca and Cc are connected in series. Therefore, the total capacitance can be determined by the following formula:

$$C = \frac{Ca\times Cc}{Ca+Cc}$$

The standard capacitance tolerance is 20%(M); however, capacitors with a capacitance tolerance of 10%(K), etc. are also manufactured for special usage. The capacitance of aluminum electrolytic capacitors changes with temperature and frequency of measurement, so the standard has been set to a frequency of 120Hz and temperature of 20℃.

1-5-2 Dissipation factor (Tan δ)

The Tan δ is the ratio of the resistive component (R_{ESR}) to the capacitive reactance (1/ωC) in the equivalent series circuit.

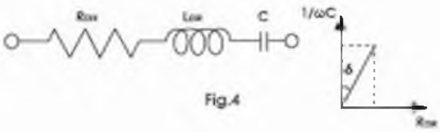


Fig.4

$\tan\delta = R_{ESR}/(1/\omega C) = \omega C R_{ESR}$

where : R_{ESR}=ESR at 120Hz

$\omega = 2\pi f$

f = 120Hz

The Tan δ shows higher values as a measuring frequency increases and a measuring temperature decrease.

1-5-3 Equivalent series resistance (ESR)

The equivalent series resistance (ESR) represents all of the ohmic losses of the capacitor. In the equivalent circuit, it is connected in series with the capacitance. The ESR originates from the ohmic resistances of the electrode foils, the electrolyte, the leads and each internal connection.

The ESR declines with increasing temperature, and also declines steadily with increasing frequency at low frequencies.

1-5-4 Impedance (Z):

The impedance is the resistance which opposes the flow of alternating current at a specific frequency. It is related to capacitance (C) and inductance (L) in terms of capacitive and inductive reactance, and also related to the ESR. It is expressed as follows:

$$Z = \sqrt{ESR^2 + (X_L - X_C)^2}$$

Where: $X_C = 1/\omega C = 1/2\pi fC$

$X_L = \omega L = 2\pi fL$

1-5 基本参数和术语

1-5-1 电容量

阴极箔电介质部分的容量可以用下列公式进行计算:

$$Ca = 8.855\times10^{-8}\frac{\varepsilon\cdot A}{d}\ (uF)$$

阴极箔的容量Cc决定于氧化膜介质的特性，阴极箔的氧化膜可由电压化成生成，或者储存期间自然生长而成（通常阴极箔的氧化膜耐压小于1V）。根据铝电解电容器的结构，Ca 和Cc是串联在一起的，因此，电容器的总容量可用下列公式得出:

$$C = \frac{Ca\times Cc}{Ca+Cc}$$

标准的容量允许公差为±20% （M），不过，诸如公差为±10%（K）等特殊用途的电容器也是可以生产的。铝电解电容器的容量会随测试温度和频率而变化，因此，设定测试的标准条件为120Hz，20 ℃。

1-5-2 损耗角正切（Tan δ）

在等效电路中，等效串联电阻ESR同容抗1/ωC之比称之为Tan δ。

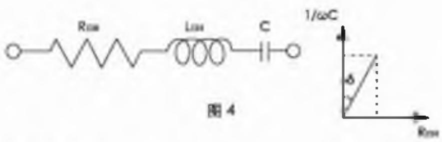


图 4

$\tan\delta = R_{ESR}/(1/\omega C) = \omega C R_{ESR}$

其中：R_{ESR}=ESR（120 Hz）

$\omega = 2\pi f$

f =120Hz

Tan δ 随着测量频率的增加而变大，随测量温度的下降而增大。

1-5-3 等效串联电阻（ESR）

等效串联电阻（ESR）是表征电容器全部欧姆损耗的量值。在等效电路中，它与容量串联。等效串联电阻的欧姆电阻来自于电极箔、电解液、引线的电阻及它们之间的连接电阻。

ESR随温度上升而下降.在低频区也随频率的上升而降低。

1-5-4 阻抗（Z）：

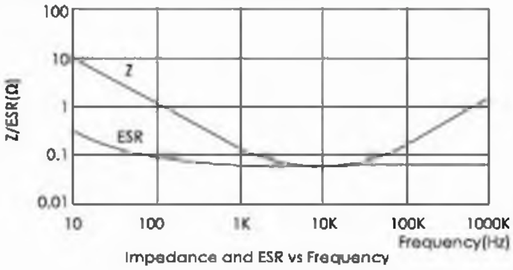
在特定的频率下，阻碍交流电通过的电阻就是所谓的阻抗（Z）。它与容量和电感所对应的容抗和感抗有关，也与等效串联电阻ESR有关。具体表达式如下:

$$Z = \sqrt{ESR^2 + (X_L - X_C)^2}$$

其中：$X_C = 1/\omega C = 1/2\pi fC$

$X_L = \omega L = 2\pi fL$

A typical impedance-versus-frequency curve is shown below. It takes on its minimum value at the self-resonant frequency, and the impedance is equal to the ESR at that frequency.



Impedance and ESR vs Frequency

Fig.5

1-5-5 Leakage current:

Leakage Current is the DC current flowing through the capacitor with the rated voltage applied. The value of leakage current depends on the voltage applied, the charging period and capacitor temperature. The leakage current shows higher values as the temperature and voltage increase.

The leakage current value can be decreased by proper selection of materials and production methods; however, cannot be totally eliminated.

The specified leakage current value is measured after the rated voltage of the capacitor is applied at room temperature for a specified time period.

1-5-6 Ripple current

Ripple current is the alternating current flowing through a capacitor. This current causes an internal temperature rise due to power losses in the capacitor. The rated ripple current are specified for an expected temperature rise at rated temperature, under which the capacitor will operate normally during the whole lifetime period.

Generally, the 85℃ type capacitors permit a temperature rise of 10℃ and have a maximum permitted core temperature of 95℃ . The 105℃ type capacitors permit a temperature rise of 5℃ and have a maximum core temperature of 110℃. Actual maximum permitted core temperatures vary by type and manufacturer.

When operating temperature decreases, the maximum permitted core temperature rises, in the other word, the rated ripple current could be increased when the actual operating temperature is less than the rated temperature. However, too much temperature rise will cause the capacitor to exceed its maximum permitted core temperature of each ambient temperature and fail quickly, operation close to the maximum permitted core temperature will dramatically shorten expected life. The following shows a guide limit of maximum core temperature rise (ΔT) at each ambient temperature for a 105℃ maximum rated products.

Table 2

Ambient temperature Ta (℃)	40	55	65	85	105
Guide limit of ΔT (℃)	30	30	25	15	5
Core temperature Ta + ΔT	70	85	90	100	110

In most applications, there is more than one frequency for the ripple current. In this cases, the r.m.s. (root mean square) value of the ripple currents needs to be considered, because currents of all frequencies contribute to the self-heating:

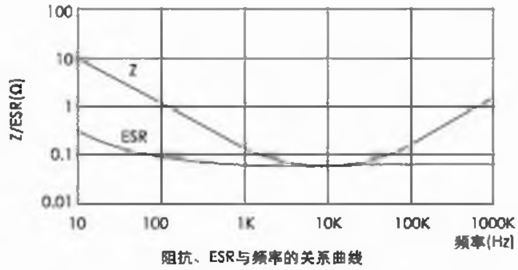
$$Ia=\sqrt{\left(\frac{If1}{Ff1}\right)^2+\left(\frac{If2}{Ff2}\right)^2+\cdots+\left(\frac{Ifn}{Ffn}\right)^2}$$

Ia: r.m.s. value of the rated ripple currents
If1 ··· Ifn: r.m.s.values of ripple currents at frequenciesf1···fn
Ff1··· Ffn: correction factor for the current at frequencies f1···fn

$Ffi=\sqrt{\frac{ESR(fo)}{ESR(fi)}}$ where fo= reference frequency of the nominal ripple current

The typical frequency multipliers are shown in the specification.

下图中标出的是典型的阻抗频率曲线。谐振频率点出现最小值，该频率点的阻抗与ESR值相等。



阻抗、ESR与频率的关系曲线

图5

1-5-5 漏电流:

漏电流即是在施加了电压后流经电容器的直流电流。电流值与施加的电压，充电时间和电容器的温度有关。温度升高、电压升高都会使漏电流增大。

漏电流的值可以通过合适的材料和生产方式来加以降低，但它不能被完全消除。

漏电流规格值是在室温条件下和规定的时间内对电容器施加了额定电压之后测得的。

1-5-6 纹波电流

纹波电流即是在电容器内流过的交流电流。由于电容器内的功率损耗，纹波电流会使电容器内部产生一个温升。为了使电容器在寿命周期内正常工作，每个电容器都规定了一个额定工作温度下的额定纹波电流，从而限制其内部温升。

通常85℃的电容器允许的最高温升为10℃，即芯包中心最高允许温度为95℃；105℃的产品，允许的最高温升为5℃，芯包中心最高允许温度可到110℃。不同种类电容和不同制造厂家，实际的允许纹波电流也有所不同。

当工作温度下降时，中心最大允许温升可以增大，也就是说，当实际工作温度小于额定温度时，电容器的额定纹波电流可以上升。然而，过大的温升会导致电容器内部温度超出各环境温度下的最大允许温度而快速失效，工作时的内部温度太接近最大允许温度将严重缩短电容器的预期寿命。下表给出了额定温度为105℃的产品在各环境温度下的最大允许温升（ΔT）。

表2

环境温度 Ta (℃)	40	55	65	85	105
最大温升 ΔT (℃)	30	30	25	15	5
中心温度 Ta + ΔT	70	85	90	100	110

在多数应用场合，纹波电流的频率不止一个。这种情况下，必须考虑纹波电流的均方根值，因为电容器的自身发热是由所有频率的纹波电流共同引起的:

$$Ia=\sqrt{\left(\frac{If1}{Ff1}\right)^2+\left(\frac{If2}{Ff2}\right)^2+\cdots+\left(\frac{Ifn}{Ffn}\right)^2}$$

Ia：纹波电流的均方根值
If1 ··· Ifn：在频率f1···fn下的纹波电流均方根值
Ff1··· Ffn：在频率f1···fn时的纹波电流修正系数

$Ffi=\sqrt{\frac{ESR(fo)}{ESR(fi)}}$ 此处fo= 标称纹波电流的参考频率

典型频率的纹波电流修正系数已在具体规范中列出.

1-5-7 Rated Voltage

Rated voltage is the maximum peak voltage including ripple voltage that may be applied continuously between the terminals of the capacitor over the specified temperature range. When a ripple current is applied to the capacitor, the sum of the peak ripple voltage and the bias DC voltage should not exceed the rated voltage, namely

$U_{IP}+U_B \leqslant U_R$, where:

U_{IP}: peak ripple voltage

U_B: bias DC voltage

U_R: rated voltage

Capacitors with higher rated voltage could replace the lower rated voltage capacitors as long as case size and electrical perfomances are also compatible.

1-5-8 Recovery Voltage (Dielectric Absorption)

After charging and then discharging aluminum electrolytic capacitors, a voltage between the two terminals will appear after some time. This voltage may reach levels of 15 ~ 25% of the originally applied voltage and it is called recovery voltage. Its existence is related to the phenomenon of dielectric absorption.

Once the recovery voltage is present, sparks may scare the workers during assembly, and low-voltage components (CPU, memory, etc.) may be affected. Measures to prevent this are to discharge the accumulated electric charge by a resistor of about 100Ω to 1kΩ before usage, or to ship out the capacitors with short-circuited terminals, e.g. by covering them with an aluminum foil or a conductive plastic cover at the production stage. Please consult us for adequate procedures.

2. To calculate balance resistance when connecting in series

In order to use capacitors at higher voltages than rated voltage it is necessary to connect them in series. Due to differences in leakage currents between individual capacitors, parallel resistors for each capacitor may be required, cf. Fig6.

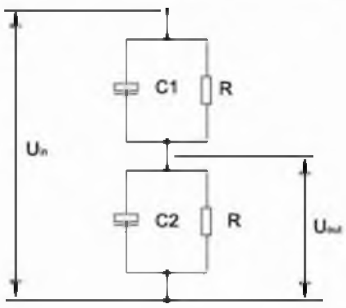


Fig.6

The current IR through the resistor R must be larger than the leakage current in order to control the even split of the voltage. If we suppose the leakage current IL to be 0.003CU (normally it is considerably less than this), and let IR be five times larger than IL, then the value of the balancing resistor R can be calculated by the following equation:

$R=U_C/(5 \times I_L)=U_C/0.015CU_C=1/0.015C$
(Unit: R——Ohm; Uc——Volt; C——Frad)

Example: calculation of the value of the balancing resistor in case of connecting two CD_293_BZ, 400V, 330μF capacitors in series.

$R=1/0.015C=1/(0.015 \times 330 \times 10^{-6})=202K\Omega$

1-5-7 额定电压:

额定电压是在整个温度范围内可以连续施加在电容器两个端子上的包括纹波电压在内的最高峰值电压。当电容器上施加纹波电流时，纹波电压峰值与偏置直流电压的叠加值应不大于电容器的额定电压，即

$U_{IP}+U_B \leqslant U_R$，此处:

U_{IP}：纹波电压峰值

U_B：偏置直流电压

U_R：额定电压

只要壳号电性能是一致的，那么额定电压较高的电容器均可代替额定电压较低的电容器。

1-5-8 再生电压（介质吸收）

电容器充电后将电放掉，过一段时间端子间又会产生电压，电压值能够达到原先施加电压的15~25%，这个电压被称为再生电压，其存在与介质吸收现象有关。

一旦出现再生电压，产生的打火会惊吓到装配线的工人，低压部件（如CPU、内存等）可能会受到影响。预防的措施是在使用前用100 ~1KΩ的电阻将电容器上累积的电荷放掉，或者是在运输时把电容器端子短路起来，比如，生产时在电容器上覆盖一张铝箔或导电塑料盖。如需了解更多细节，请与我们联系。

2. 电容器串联均衡电阻计算:

为了在高于额定电压的更高电压下使用电容器，必须将其进行串联。由于每个电容器的漏电流不同，因此就需要在每个电容器上并联电阻。如图6。

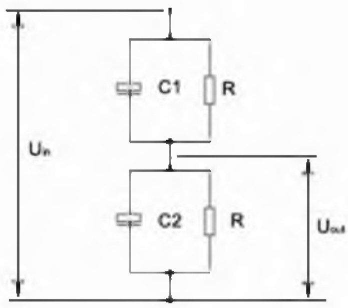


图6

流过电阻R的电流IR必须远大于电容器的漏电流，以便控制电压的均等分布。假定流过电阻R的电流为电容器漏电流的5倍，而电容器的稳定漏电流IL设定为0.003CUC（实际漏电流小于该值），则均压电阻的计算公式为:

$R=U_C/(5 \times I_L)=U_C/0.015CU_C=1/0.015C$
(单位：R——Ω；Uc——V：C——F)

例：计算2只CD293 400V330uF 电容器串联时的均压电阻值。

$R=1/0.015C=1/(0.015 \times 330 \times 10^{-6})=202K\Omega$

3. About the Life of an Aluminum electrolytic Capacitor

3-1 Definition and the test conditions of the lifetime

Lifetime is the answer to the question "How long will the capacitor survive in my application?" The end of the lifetime is reached when certain parameters exceed pre-defined threshold values.It is common practice to allow a certain portion of species to be outside of the limits (outlier percentage). A deviation of certain parameters from pre-defined ranges does not mean a total loss of the capacitor's function, but the design of the application should be done in a way to ensure to function properly even under these unfavorable conditions.

In addition to the more practically oriented "useful life" figure, Jianghai also publishes well-defined specifications of "load life" and "endurance" to increase the transparency for the end user. Shelf life test results are also provided to give an indication of the chemical stability of the electrolytic capacitors and to complete the full picture of each capacitor series(Table 3). When comparing lifetime data for capacitors from different manufacturers, please note that other definitions may apply – even if the same terms are used.

3. 铝电解电容器的寿命

3-1 寿命的定义和测试条件

使用寿命是对下面这个问题的回答："在我的应用过程中，电容器能保持多长时间不失效？"当某些参数超出了预先的规定值时，即可认为是达到了寿命的终点。但一般说来，实际使用时某些指标超标（某种比例的异常值）是允许的。也就是说，某一参数偏离了预先规定的范围，并不意味着电容器的功能已全部丧失，但是在根据应用要求进行设计时，必须要确保即使在电容器参数超标的不利条件下，设备也能正常工作。

除了较为实用的"使用寿命"数据外，江海还标出了明确的"负载寿命"和"耐久性"指标，以增加对最终用户的透明度。同时还提出了"储存寿命"的测试结果，以表明电解电容器的化学稳定性，并对每个系列的电容器作出了完整的描述（表3）。请注意，当与其他制造商进行寿命数据比较时，即使对于相同的名称，也应同时提供其他具体的定义。

	Useful Life 使用寿命		Load Life 负载寿命	Endurance Test 耐久性测试	Shelf Life 储存寿命	
Lifetime 寿命	7000h	＞200000h	5000h	5000h	1000h	
Leakage Current 漏电流	Not more than specified value 不超过规定值		Not more than specified value 不超过规定值	Not more than specified value 不超过规定值	Not more than specified value 不超过规定值	
Capacitance Change 容量变化	Within ±30% of initial value 初始值的±30%以内		Within ±20% of initial value 初始值的±20%以内	Within ±20% of initial value 初始值的±20%以内	Within ±20% of initial value 初始值的±20%以内	
Dissipation Factor 损耗	Not more than ±300% of specified value 不超过规定值的±300%		Not more than ±200% of specified value 不超过规定值的±200%	Not more than ±130% of specified value 不超过规定值的±200%	Not more than ±200% of specified value 不超过规定值的±200%	
Condition 条件: Applied Voltage 施加电压 Applied Current 施加电流 Applied Temperature 施加温度	U_R I_R 105℃	U_R 1.6×I_R 40℃	U_R I_R 105℃	U_R I_R=0 105℃	U_R I_R=0 105℃	After test: U_R to be applied for 30min, >24h before measurement. 试验后施加电压U_R30分钟，过24小时后测试。

Table 3: Full definition of test conditions and allowed ranges
表3 测试条件和允许范围的完整定义

Definitions and terms that are used by Jianghai to describe the lifetime:

1) Useful life

The useful life test procedure comes close to the actual operating conditions in the application: in addition to the d.c. bias voltage and the presence of the upper category temperature, a ripple voltage is superimposed that causes additional thermal stress by self-heating. The test is terminated when 1% of the items under test are outside of the specified parameter limits.

2) Load Life

The load life test has similar test conditions like the useful life test, but the acceptance criteria are stricter than for the useful life test. Additionally, all of the items have to fulfill the test criteria.

江海描述电容器寿命所用的定义和条件：

1）使用寿命：

使用寿命的测试步骤与应用中的实际操作条件相似：除了直流偏压和上限温度之外，还叠加了一个纹波电压，由于自身发热，这个电压会引起额外的热应力。当有1%的被测产品的指标参数超过极限值时，该测试终止。

2）负荷寿命

负载寿命测试的条件与使用寿命的测试条件相仿，但接受标准比使用寿命测试更为苛刻。另外，所有被测产品均应达到测试标准。

3) Endurance

The method for conducting an endurance test is described in the IEC60384-4 standard: the capacitors are operated at their rated voltage and at their upper category temperature and the time course of their electrical parameters (capacitance, ESR, leakage current) is observed until certain thresholds are exceeded. All of the items under test have to fulfill the test criteria.

4) Shelf Life

A good indicator to assess the chemical stability of electrolytic capacitors is the "shelf life". As opposed to the regular storage of capacitors at moderate temperatures, the shelf life test is a demanding accelerated life test that subjects the test specimens for a pre-defined period to their upper category temperature without any voltage applied. Without any voltage applied, the capacitor cannot benefit from any self-healing during the test – this particular feature makes the shelf life test quite tough. Vital parameters like leakage current, capacitance, and dissipation factor must stay within predefined limits after the test. A high numerical value of the shelf life is a good indicator for chemical stability, high purity of the materials and an advanced production quality.

3-2 lifetime Estimation of the Aluminum electrolytic capacitor

3-2-1 Self-heating of the aluminum electrolytic capacitor during operation.

During operation, the ripple current flowing through the aluminum electrolytic capacitor will generate heat due to the series equivalent resistance(ESR) of the capacitor. The generated heat will be:

$$P=I^2R \cdots\cdots\cdots\cdots (1)$$

Where I: Ripple current (Arms)

R: ESR (Ω)

The heat will cause a core temperature rise of the capacitor as below:

$$\Delta T=\frac{I^2 \cdot R}{A \cdot H} \cdots\cdots\cdots\cdots (2)$$

Where ΔT: Temperature Increase In the capacitor core (deg.)

I: Ripple current (Arms)

R: ESR (Ω)

A: Surface area of the capacitor (cm^2)

H: Radiation coefficient (Approx. $1.5\sim2.0\times10^{-3}W/cm^2\times℃$)

The above equation (2) shows that the temperature of a capacitor increase in proportion to the square of the applied ripple current and ESR, and in inverse proportion to the surface area. Therefore, the amount of the ripple current determines the heat generation, which affects the life. The value of permissible ΔT varies depending on the capacitor types and operating conditions. The usage is generally desirable as ΔT remains less than 10℃ for 85℃ products and 5℃ for 105℃ products and higher temperature products at their rated temperature.

In practice, since it is not so easy to measure the core temperature for the small size capacitors, the measurement of the surface temperature at the can bottom provides a good approximation of the core temperature value for radial and snap-in capacitors with can sizes up to 35 mm in diameter. The factors given below in table 4 can be used to estimate the core temperature rise based on the surface temperature rise.

Case diameter	~10	12.5~16	18	22	25	30	35
Core/Surface	1.1	1.2	1.25	1.3	1.4	1.6	1.65

Table 4: core temperature rise multipliers for various can diameters

3）耐久性测试

进行耐久性测试的方法已在IEC60384-4标准中做了描述。对所有的电容器施加额定电压，并置于上限温度中。在整个测试时段中观察它们的电参数（容量、ESR、漏电流）情况，直至某些参数超出极限值。所有被测试电容器均应达到测试标准。

4）储存寿命

用来评估电解电容器化学稳定性的最好办法就是进行储存寿命测试。与在常温下进行常规储存不一样的是，这种储存寿命测试是一种要求很高的加速寿命测试方法；在不加电压的情况下，将测试样品在上限温度条件下放置规定的时间。不加电压，电容器在测试过程中也就无法得到自愈——所以，这一特点使储存寿命测试变得十分严酷。测试后诸如漏电流、容量、损耗等关键参数均必须保持在规定的极限范围内。储存寿命时间长则表明了电容器有较好的化学稳定性、材料的纯度高、生产技术先进。

3-2 铝电解电容器的寿命估算

3-2-1.铝电解电容器工作时的自身发热

在工作时，由于电容器内部存在内阻（ESR），流过的纹波电流会引起电容器的发热。产生的热量可由下式计算

$$P=I^2R \cdots\cdots\cdots\cdots (1)$$

I：纹波电流（Arms）

R：等效串联电阻（Ω）

$$\Delta T=\frac{I^2 \cdot R}{A \cdot H} \cdots\cdots\cdots\cdots (2)$$

发热会引起电容器中心的温升，表示如下：

其中，ΔT: 电容器中心的温升（℃）

i: 纹波电流 (Arms)

R: ESR (Ω)

A: 电容器的表面积(cm^2)

H: 散热系数($1.5\sim2.0\times10^{-3}W/cm^2\times℃$)

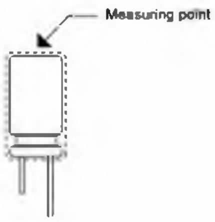
上面公式（2）显示电容器的温度上升与纹波电流的平方以及等效串联电阻ESR成正比，与电容器的表面积及散热系数成反比，因此，纹波电流的大小决定着产生热量的大小，从而影响其使用寿命，电容器的类型以及使用条件决定了可允许的ΔT值的大小，一般情况下，85℃产品，ΔT≤10℃。105℃或更高温度产品ΔT ≤5℃。

实际应用中，由于测试小尺寸电容器的中心温度并不是很容易，因此引线式电容器和35mm以下的Snap-in电容器，中心的温升可以通过测试电容器底部温升来近似得到。下表4可以用来根据表面温升估算中心温升。

直径	~10	12.5~16	18	22	25	30	35
中心温升/表面温升	1.1	1.2	1.25	1.3	1.4	1.6	1.65

表-4 不同直径电容器中心温升系数

The measuring point for temperature increase due to ripple current is shown below:



For larger can sizes snap-in and screw type capacitors, to get more accurate results, a direct measurement of the core temperature by means of a thermocouple is recommended.

Jianghai supplies capacitors with pre-mounted thermocouple for evaluation purposes on request.

3-2-2 Estimation of lifetime calculation

(1) The life equation considering the ambient temperature , the measured core temperature rise cause the by the ripple current and the applied voltage will be:

$$L=L_o \times 2^{\left(\frac{T_o-T}{10}\right)} \times K^{\left(\frac{\Delta T_o-\Delta T}{10}\right)} \times \left(\frac{U_r}{U_a}\right)^n \text{ ....(3)}$$

Where Lo: Life at the rated temperature with the rated ripple current (h)

To: Rated operating temperature (℃)

T: Actual operating temperature (℃)

K: Ripple acceleration factor

(K=2, if within allowable ripple current)

(K=4, if exceeding allowable ripple current)

△To: Temperature rise at capacitor core, at the rated temperature (℃)

△T: Temperature rise at capacitor core at the actual operating temperature(℃)

Ur: Rated working voltage(V)

Ua: Actual working voltage(V)

n: exponent, for small size radial type capacitors n=0; for medium and large size capacitors, n=2.5 the actual working voltage is defined as: 0.6Ur≤Ua≤Ur

Operating voltage below 0.6Ur is considered to be 0.6Ur in the calculation.

(2) The life equation considering the ambient temperature ,the ripple current and applied voltage will be a conversion of the above equation (3), as below:

$$L=L_o \times 2^{\left(\frac{T_o-T}{10}\right)} \times K^{\left[1-\left(\frac{I}{I_o}\right)^2\right] \times \frac{\Delta T_o}{10}} \times \left(\frac{U_r}{U_a}\right)^n \text{ ....(4)}$$

Wherein Io: Rated ripple current at the rated operating temperature (Arms)

I: Actual applied ripple current (Arms)

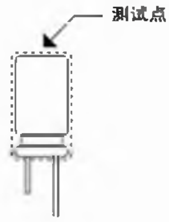
The life expectancy formula shall in principle be applied to the temperature range between the ambient temperature of +40℃ and maximum allowable working temperature. The expected life time shall be about fifteen years at maximum as a guide in terms of deterioration of the sealant.

4. Reliability

4-1 The bathtub curve:

Aluminum electrolytic capacitors feature failure rates shown by the following bathtub curve.

下图表示纹波电流引起的温升的测量点



对大尺寸的snap-in和screw电容器，为了使测试结果更精确，建议使用热电偶直接测量中心温度。

江海可以根据客户的要求提供预先埋好热电偶的电容器用于产品评估测试。

3-2-2 寿命估算

（1）考虑环境温度、纹波电流发热和施加电压的寿命公式为：

$$L=L_o \times 2^{\left(\frac{T_o-T}{10}\right)} \times K^{\left(\frac{\Delta T_o-\Delta T}{10}\right)} \times \left(\frac{U_r}{U_a}\right)^n \text{ ....(3)}$$

其中，L0：最高温度和额定纹波电流下的寿命（h）

T0：额定工作温度(℃)

T：实际工作温度(℃)

K：纹波电流加速因子

（K=2，纹波电流在允许的范围内）

（K=4，纹波电流超过允许范围时）

△T0：额定温度时电容器中心允许温升(℃)

△T：实际工作温度下电容器的中心温升(℃)

Ur: 额定工作电压(V)

Ua: 实际工作电压(V)

n：指数，对小尺寸引线式电容器，n=0；对中等尺寸和大尺寸电容器，n=2.5 实际工作电压规定如下：0.6Ur≤Ua≤Ur

工作电压小于0.6Ur时，计算时取0.6Ur。

2）考虑环境温度、纹波电流和工作电压的寿命公式可由上面（3）式转化得到，如下式：

$$L=L_o \times 2^{\left(\frac{T_o-T}{10}\right)} \times K^{\left[1-\left(\frac{I}{I_o}\right)^2\right] \times \frac{\Delta T_o}{10}} \times \left(\frac{U_r}{U_a}\right)^n \text{ ....(4)}$$

其中，I0：额定工作温度下的额定纹波电流（Arms）

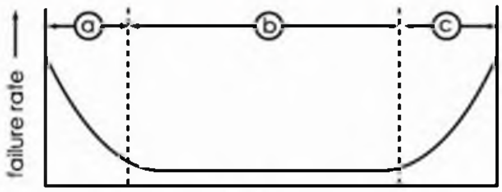
I：实际施加的纹波电流（Arms）

寿命的推算公式，原则上适用于周围环境温度为+40℃到最高工作温度范围内，但从封口材料老化这个角度考虑，实际的预期寿命原则上最大为15年。

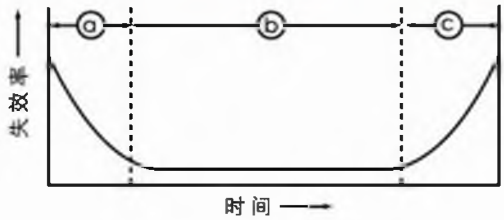
4. 可靠性

4-1 浴缸曲线

铝电解电容器的失效率特征可以用下图的浴缸曲线来描述



bathtub curve



浴缸曲线

A Infant failure period

This is a period during which failures are caused by deficiencies in design, structure, manufacturing process or severe misapplications. Such failures occur soon after the components are exposed to circuit conditions. In aluminum electrolytic capacitors, these failures are either corrected through aging process reforming or repairing a damaged oxide layer, or found by the aging process, removed by the sorting process, and thus do not reach the field.

Infant failures due to capacitor misapplication such as inappropriate ambient conditions, over-voltage, reverse voltage or excessive ripple current can be avoided with proper circuit design and installation.

B Useful life period

This is a random failure period during which the failure rate is the lowest. These failures are not related to operating time but to application conditions. During this period, non-solid aluminum electrolytic capacitors show a slow decrease in capacitance and a slow increase in tanδ and ESR, which are caused by a small loss of electrolyte, and feature fewer catastrophic failures than semiconductors and solid tantalum capacitors.

C wear-out failure period

This is a period during which the properties of a component extremely deteriorate, and the failure rate increases with time. Non-solid aluminum electrolytic capacitors end their useful life during this period.

4-2. Failure types:

The two types of failures are classified as catastrophic failures and wear-out failures as follows.

① Catastrophic failure

Like a short circuit or open circuit failure, this is a failures mode which destroys the function of the capacitor.

② Wear-out failure

This is a failure mode resulted by the gradual deterioration of the capacitor electrical parameters. The criteria for judging the failures varies with application and design factors.

Capacitance decrease and tanδ increase are caused by the loss of electrolyte in the wear-out failure period. This is due primarily to loss of electrolyte by diffusion (as vapor) through the sealing material. Gas molecules can diffuse out through the material of the end seal. if the electrolyte vapor pressure within the capacitor is increased, by high temperatures for example, the diffusion rate is increased. Swelling of the seal material by electrolyte vapor pressure may also occur at elevated temperature. This swelling may further enhance diffusion and mechanically weaken the seal.

A 早期失效期

早期失效阶段是由于在设计、结构、制造工艺中存在缺陷或由于严重的使用不当而造成产品失效的阶段。这种失效在元件通电后不久就会被发现。在铝电解电容器中，这种失效要么通过老化过程中对损坏的氧化膜重新化成或修补得以避免，要么在老化过程中被发现，在测试分选时被剔除，因此不会进入使用领域。

由于使用环境不当、过电压、施加反向电压或纹波电流过大等使用不当引起的早期失效，可以通过适当的电路设计和安装方法加以避免。

B 使用寿命期

这是一个随机的失效阶段，通常该阶段的失效概率很低。这种失效与工作环境有关，与工作时间关系不大。在此阶段，非固体电解质电容器表现为容量缓慢下降，损耗和ESR逐渐上升，这是由于电解液量逐渐减少引起的，很少会出现半导体和固体钽电容器那种致命性的失效。

C 耗损失效期

该阶段，元件的性能急剧恶化，失效率随时间而上升。非固体铝电解电容器在此阶段结束其使用寿命。

4-2. 失效类型：

失效的类型分为两种，致命性失效和耗损性失效。

① 致命性失效

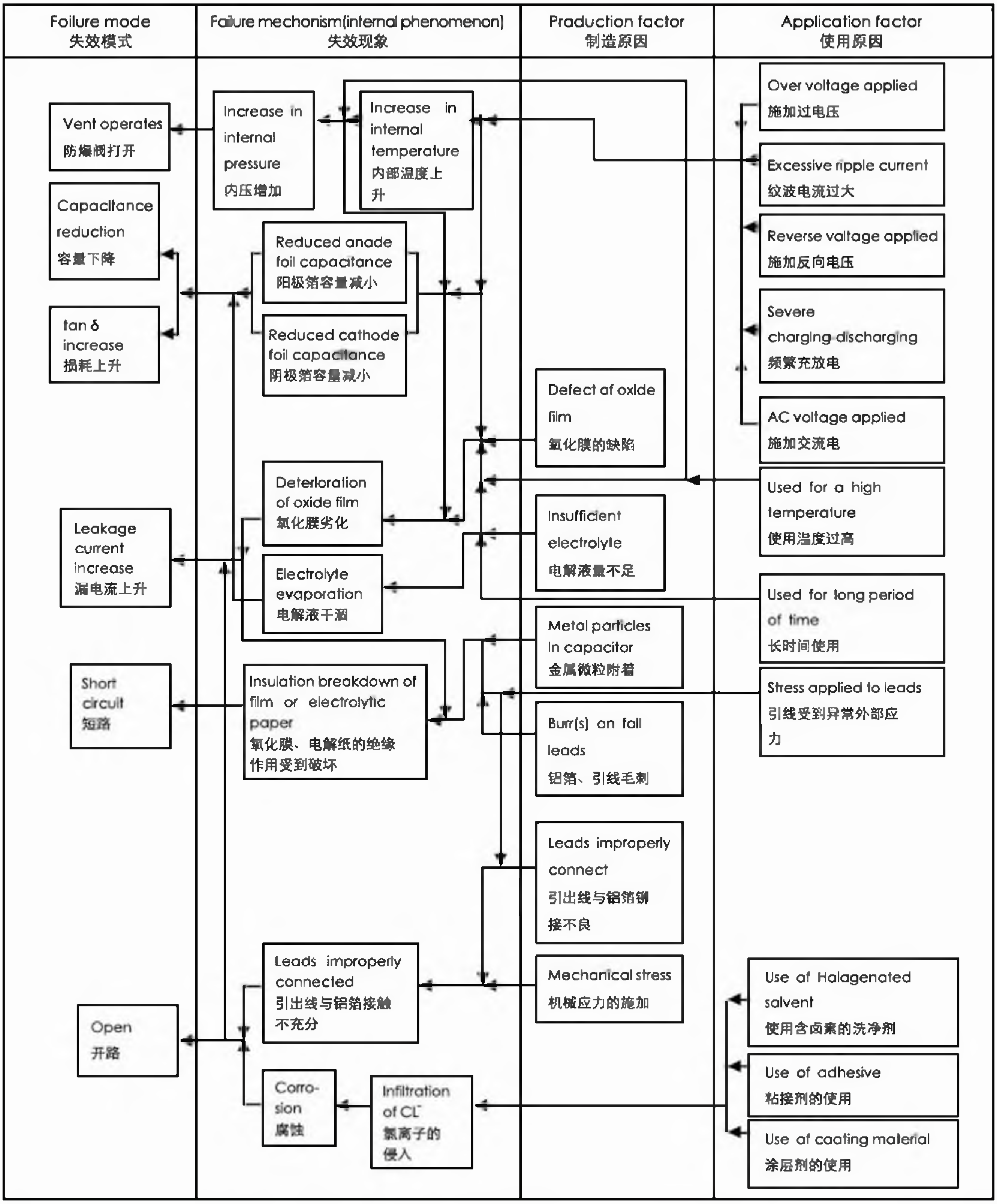
诸如短路和开路失效，这种失效模式破坏了电容器的使用功能

② 耗损性失效

这是一种由于电容器电参数逐渐恶化而造成的失效，判断失效的标准也随应用和设计参数的不同而改变。

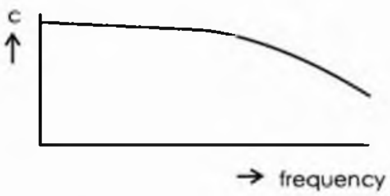
耗损失效阶段，由于电解液的减少，容量下降，损耗角正切上升。这是由于电解液以蒸汽形式从封口材料散失而造成的，气体分子能够穿过封口材料而散失，如果由于高温等原因使电容器内部蒸汽压力上升，则扩散的速度也会上升。温度上升造成的电解液蒸汽压力也会导致封口材料的膨胀，这种膨胀可能进一步加强电解液的渗透，同时削弱密封作用。

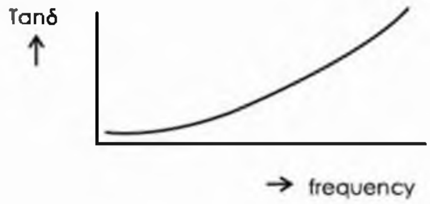
4-3 Typical failure modes and factors of aluminum electrolytic capacitors
铝电解电容器失效模式及原因分析

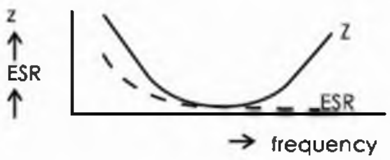


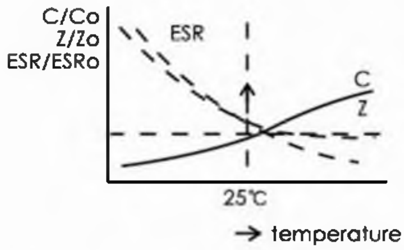
5. Electrical behaviour
电气特性

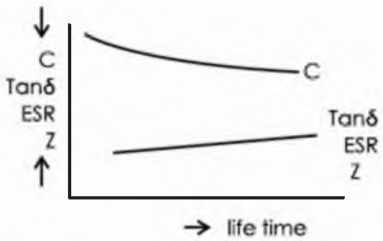
Characteristics of electrical capacitors vary wity temperature, time, and appiied voltage.
电容器的电气特性与温度，时间，以及印加电压的关系

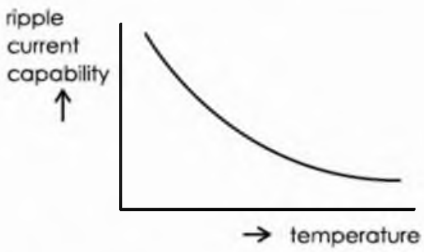


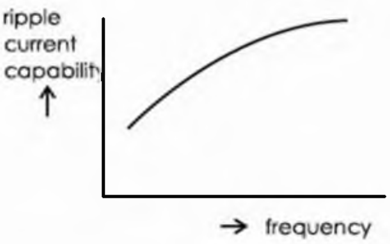


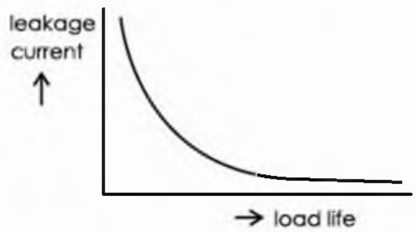


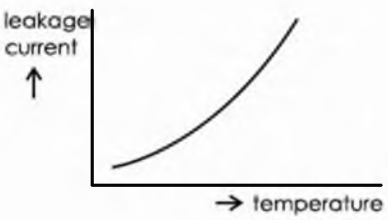


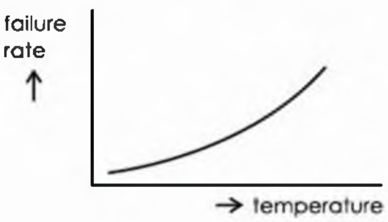


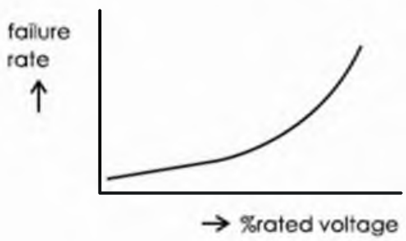












6. Application Guidelines

6-1. Circuit Design

(1) Please make sure the application and mounting conditions to which the capacitor will be exposed are within the conditions specified in the catalog or alternate product specification (Referred as to specification here after).

(2) Operating temperature and applied ripple current shall be within the specification.

The capacitor shall not be used in an ambient temperature which exceeds the operating temperature specified in the specification.

Do not apply excessive current which exceeds the allowable ripple current.

(3) Appropriate capacitors which comply with the life requirement of the products should be selected when designing the circuit.

(4) Aluminum electrolytic capacitors are polarized. Make sure that no reverse voltage or AC voltage is applied to the capacitors. Please use bi-polar capacitors for a circuit that can possibly see reversed polarity.

Note: Even bi-polar capacitors can not be used for AC voltage application.

(5) For a circuit that repeats rapid charging/discharging of electricity, an appropriate capacitor that is capable of enduring such a condition must be used. Welding machines and photoflash are a few examples of products that contain such a circuit. In addition, rapid charging/discharging may be repeated in control circuits for servomotors, in which the circuit voltage fluctuates substantially.

For appropriate choice of capacitors for circuit that repeat rapid charging/discharging, please consult us.

(6) Make sure that no excess voltage (that is, higher than the rated voltage) is applied to the capacitor.
Please pay attention so that the peak voltage, which is DC voltage overlapped by ripple current, will not exceed the rated voltage.

In the case where more than 2 aluminum electrolytic capacitors are used in series, please make sure that applied voltage on each capacitor will be lower than rated voltage and the voltage will be applied to each capacitor equally using a balancing resistor in parallel with the capacitors.

(7) Outer sleeve of the capacitor is not guaranteed as an electrical insulator. Do not use a standard sleeve on a capacitor in applications that require the electrical insulation. When the application requires special insulation, please contact us for details.

(8) Capacitors may fail if they are used under the following conditions:
① Environmental (climatic) conditions
(a) Being exposed to water, high temperature & high humidity atmosphere, or condensation of moisture.

6. 铝电解电容器应用指南：

6-1. 电路设计

（1）首先，请确定电容器的使用和安装条件必须符合样本所供选择的产品规格中所规定的条件；

（2）工作温度和施加的纹波电流必须符合规范中的要求。
① 电容器使用时的环境温度不能超过产品规格中规定的工作温度
② 施加的纹波电流不得超过允许值

（3）在设计电路时，必须选择符合其使用寿命要求的合适的电容器

（4）铝电解电容器是有极性的，因此要确保不对电容器施加反向电压或交流电压，在可能会出现反向电压的场合，建议使用双极性电容器。

注意：即使是双极性电容器，也不能应用在交流电压的场合。

（5）对于需要反复充放电的电路而言，那就必须使用能承受这种工作环境的合适电容器。电焊机、闪光灯等设备就是如此。此外，在伺服电机等控制电路中，也会出现反复的快速充放电，电路中的电压波动很大。如果需选择具有快速充放电要求的电容器，请与我们联系。

（6）确保电容器不能在过压状态下工作（即高于额定电压）
①请注意峰值电压，即由直流电压叠加纹波电流的电压，不能超过额定电压；
②在要串联使用2个以上电容器的场合，施加在每一个电容器上的电压要低于额定电压，并用均衡电阻与每个电容器并联，使电压平均地施加到每个电容器上。

（7）电容器外面的套管不能保证做绝缘之用，所以在需要将其作为电绝缘的应用场合，这些电容器不能使用一般标准的套管。假如你的应用场合需要特殊绝缘的话，请与我们联系了解详细情况。

（8）在下列条件下使用的电容器很可能会导致失效
① 环境条件
a. 接触水，高温高湿度气候，或易产生冷凝水的地方；